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AMERICAN SOCIETY
OF CIVIL ENGINEERS

BASIC REQUIREMENTS FOR MANUSCRIPTS

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Journal of the
AIR TRANSPORT DIVISION
Proceedings of the American Society of Civil Engineers

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Papers

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MEETING USAF BLAST FENCE REQUIREMENTS[a]

Temple A. Tucker[1]

ABSTRACT

This paper is divided into two main divisions; the first a discussion of past blast fence requirements and how they have been met, the second being a discussion of a new requirement generated by the B-52 and how the Air Force is meeting it.

INTRODUCTION

Blast fences and individual scoops or blast deflectors have been used on a very limited basis for many years on the aircraft flight lines and maintenance areas at both civil and military installations. With the advent of the turbo jet engines the requirement for deflecting the aircraft wake became more important. This requirement has been met usually on the basis of individual local conditions. The result has been a wide variety of concepts and designs, most of which apparently are doing a good job. The use of blast deflectors particularly in the Air Force, has been restricted, generally, to very confined or congested areas to protect adjacent aircraft, facilities or personnel. There has been no overall requirement in the Air Force for deflectors on mass parking aprons where aircraft such as the B-47 medium bomber or the century series fighters are operated. However, the blast from the B-52 heavy bomber with its 8 J=57 jet engines operating in unison under full power has presented a new problem; thus the present large and urgent requirement for blast deflectors has been generated.

Note: Discussion open until June 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1892 is part of the copyrighted Journal of the Air Transport Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. AT 1, January, 1959.

a. Presented at the ASCE Convention, Chicago, Illinois, February 25, 1958.

1. Lt. Col. USAF, Chf. Standards Branch, Engineering Division, Dept. Dir. for Constr., Directorate of Installations, Hq USAF, Washington, D. C.

Some airport managers are already concerned with the variety of the requirements for blast protection which will arise with the introduction of jet airliners. There is no doubt that the problems which the airlines will encounter at passenger terminals will differ from those encountered at United States Air Force bases and their solutions will in all probability be much more sophisticated.

The present importance of blast fences to the Air Force is indicated by the fact that the FY 1958 Military Construction Program contains a total of 88,000 linear feet for erection on at least 25 bases. Meeting this requirement with an economically designed blast fence is the main topic of this paper.

Meeting Past Requirements

General

The aircraft industry has been the leader in developing blast protection. It is natural that the aircraft manufacturer would encounter blast problems first and practically every manufacturer has experienced a need for some measure of protection either in the plant or on the flight line. The requirement is no longer just one of preventing an annoyance but a requirement to eliminate a serious condition that is untenable for either personnel or equipment. The requirements for blast deflectors have fallen into two general categories. One being for protection of personnel, equipment and aircraft in congested areas such as parking and maintenance aprons; the second being to prevent erosion of paved or unpaved areas and to provide protection from the resulting debris. These needs have been satisfied in many ways varying from common dust palliations and simple board or sheet metal fences to more complicated scoops and vaned fences. Virtually all of the protective measures now in use by the Air Force are either those designed and developed by industry or products which have evolved from these originals.

Fences Used by Aircraft Industries

Figs. 1 thru 4 are pictures of blast fences used for jet fighters by several aircraft companies under Air Force contract at Palmdale, California. Individual scoops are also used to a great extent.

Fig. 1 shows an early fence with a heavy timber frame, timber purlins and a corrugated metal face. It is approximately 6 ft. high.

Fig. 2 shows a later similar fence of lighter construction. It has also a timber frame but is faced with corrugated asbestos board over wood sheathing.

Fig. 3 shows a precast reinforced concrete fence.

Fig. 4 shows a variation of the concrete fence, this one having a double face. The tent under the fence is used for storage of flight line equipment.

Individual Deflectors

To date experience has shown that the individual scoop is the most desirable means for deflecting the blast of fighter aircraft on Air Force bases. Deflectors for fighters are only needed for maintenance run-ups on congested aprons where aircraft movement is frequent or where parking patterns are subject to change. The portability of the scoop is the most desirable feature. They must, however, be securely tied down when in use. Fences for fighters are used occasionally in areas where the parking pattern is fairly well fixed,

Fig. 1

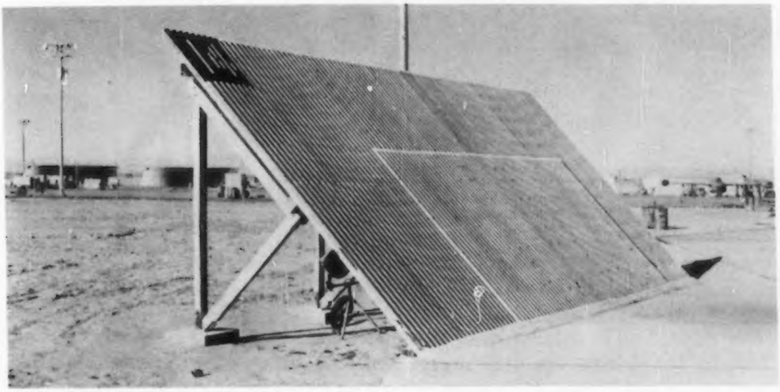


Fig. 2

Fig. 9

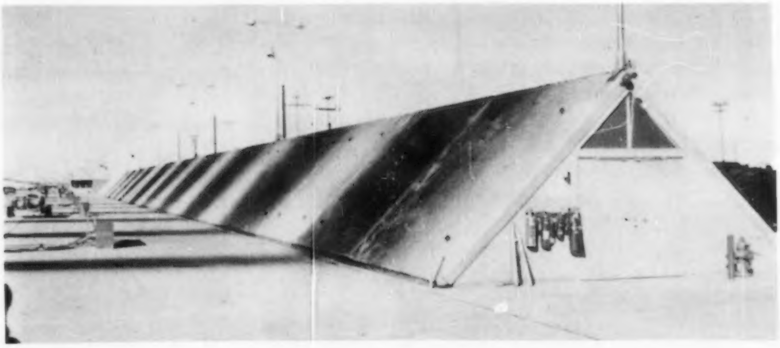


Fig. 4

Fig. 5

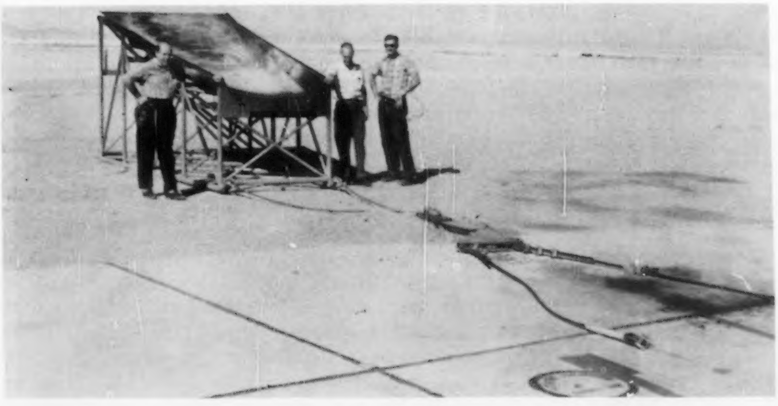


Fig. 6

such as along the edge of maintenance run-up aprons where shoulder erosions or damage to adjacent facilities is a problem.

Fences and Scoops at Air Force Bases

Figs. 5 thru 13 show both scoops and fences used at some Air Force bases for fighter blast deflection.

Fig. 5 shows an early attempt to provide a fixed scoop for single engine use at Edwards Air Force Base.

Fig. 6 is an early skid mounted scoop used at Edwards Air Force Base. Note the heavy tie-down bridle.

Fig. 7 is a more refined scoop built by an aircraft manufacturer.

Fig. 8 shows the same scoop in place behind a F-102. Note the tie-down cables attached to the main landing gear strut.

Fig. 9 shows an early fence attempt at Edwards Air Force Base made a welded steel pipe frame with bolted steel plate vanes. Note the intermediate upright plates that have been added to suppress vane flutter.

Fig. 10 shows the same fence. Note the permanent deformation in the lower vanes in the center of the picture.

Fig. 11 shows a fence installed at George Air Force Base, California on the edge of an F-100 maintenance run-up pad. This is a flat vane louvered fence.

Fig. 12 shows a single curved vane fence used behind a fighter alert shelter at McClellan Air Force Base, California.

Fig. 13 is a multiple curved vane or louvered fence behind a jet engine maintenance check stand, also at McClellan Air Force Base.

Blast Fences for Bomber Bases

Fences are considered to be the best type of blast deflector for bombers. Scoops are not considered to be practical for bomber aircraft; first since the deflected wake is a hazard to the empennage; and second, there is a problem with maneuvering and spotting both the aircraft and the scoops. The most urgent requirement for fences is on mass parking aprons where the bombers are parked tail to tail as close together as possible. The fences will allow maintenance run-up on the parking apron, thus saving a great amount of towing to remote areas and will allow the maximum use of the expensive heavy duty pavements. To better understand the blast problem it would be well to mention the fact that experience has shown that flight line maintenance of aircraft is virtually impossible and exceedingly hazardous in winds that exceed 35 miles per hour. The wake of a B-52, with all jets operating at military power exceeds this maximum wind velocity at a distance of over 600 feet behind the aircraft. Thus, it is obvious that mass parking aprons or maintenance areas would have to be expanded greatly if fences were not used. It is also possible that a B-52 being given a full power check on a parking stub which points toward a taxiway or runway, could be a menace to taxiing or landing aircraft. The wake could create a violent and extremely localized cross wind which would endanger operating aircraft. The wake of these eight powerful engines operating in unison can cause serious damage to many airfield facilities. From Castle Air Force Base, California has come a report that control tower operations have been disrupted by the wake of a B-52, parked several hundred feet away, shaking the radio antenna so violently that radio communications were garbled.

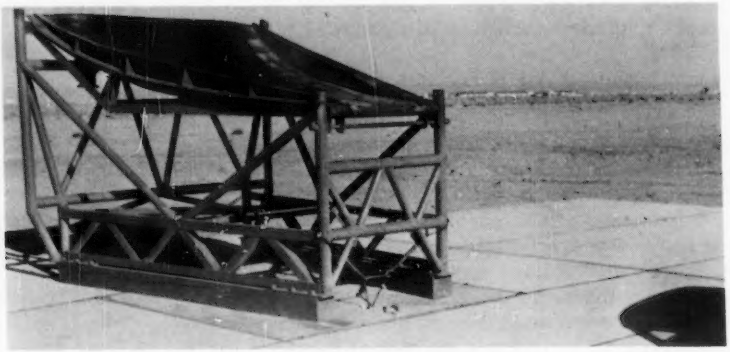


Fig. 7

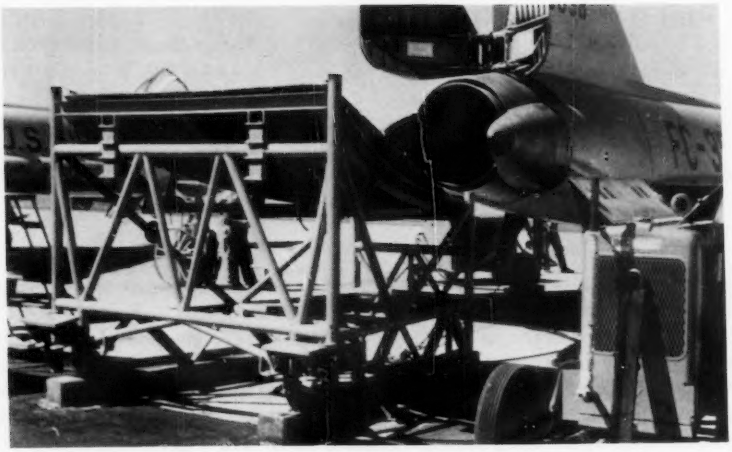


Fig. 8

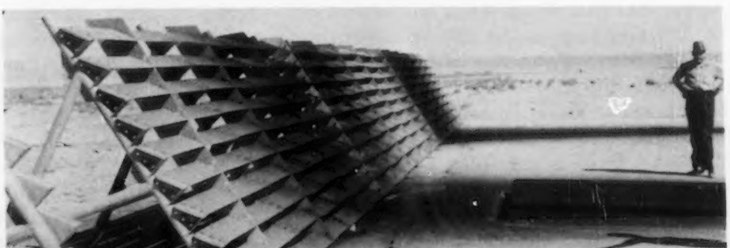


Fig. 3

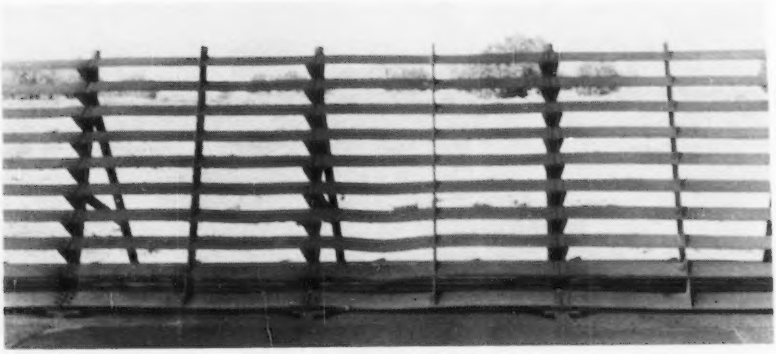


Fig. 10

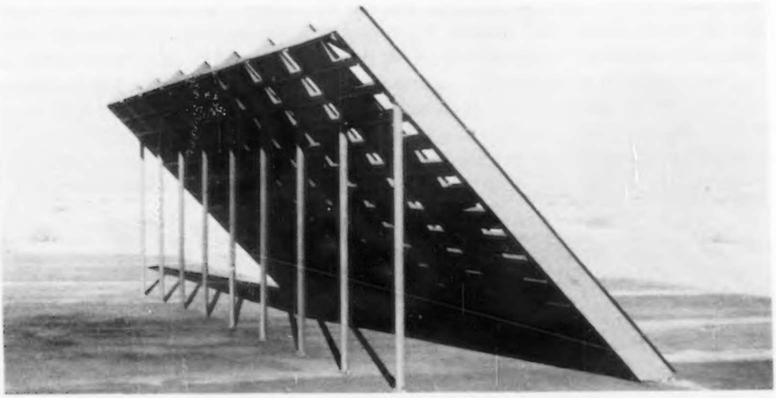


Fig. 11

Fig. 12

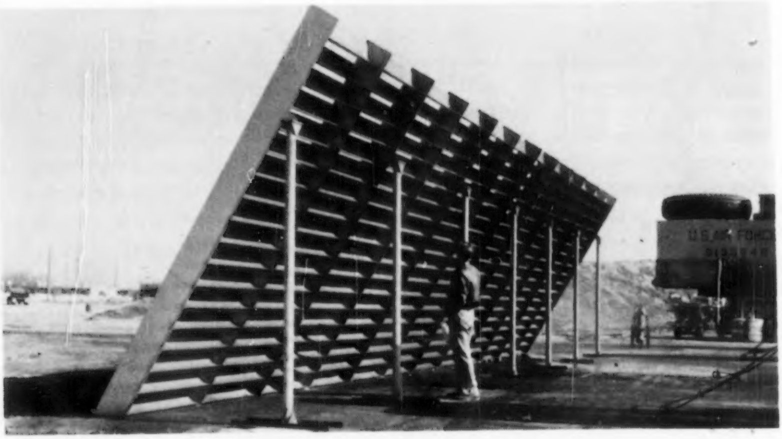


Fig. 13

Fig. 14

Fig. 15

Some Existing Fences

Figs. 14 and 15 show additional fences in use at Air Force bases.

Fig. 14 is a multiple flat vane or louvered fence behind a B-47 parking apron at March Air Force Base, California.

Fig. 15 is a multiple curved vane or louvered fence on a depot maintenance apron at Norton Air Force Base, California.

Meeting A New Requirement

General

As the inventory of the B-52 increased the requirement for blast fences increased proportionally. A large program to supply these fences was evident. Up to this time mostly field expedients had been used to solve the problem at hand. These field expedients had served their purpose to a reasonable degree but there was now the question of just how well they performed and what the cost would be for the large program. There was now a need to standardize on the most economical design that would meet the minimum requirements. The existing and proposed designs covered a variety of configurations and the cost spread was wide. There were simple configurations and the more complex cascades as have been shown on the preceding pictures. There were also some ingenious uses of surplus M-6 pierced steel plank (PSP) landing mat. These existing deflectors had cost from just a few dollars per linear foot to over $100 per linear foot.

Laboratory Testing

From existing designs the most promising were selected and subjected to scaled model tests. These tests were conducted for the Air Force in the Corps of Engineers Ohio River Division Laboratories. Models to 1/12th scale were made of mild steel and annealed. They were designed and constructed so that maximum adjustability and interchangeability of parts could be attained. The models included a single faced flat vane, double faced (tent shaped) flat vane, and a louvered fence.

a. Test Models

Fig. 16 shows the double faced model which was adjustable in angle and could accommodate solid plate (or perforated plate which simulated pierced steel plank). This same frame was also used for the single flat vane (either solid or perforated).

Fig. 17 shows the louvered model that was adjustable in spacing of the vanes, frame angle and height. It could accommodate flat vanes, curved vanes or perforated flat vanes.

b. Scope and Objective of Tests

The general scope of the test was to simulate the effect of the B-52 jet wake impining on the models. The maximum impingement temperature was 1,000 degrees Fahrenheit and the maximum gas velocity at impingement was about 1,400 feet per second. The objective of the test was to determine the effectiveness of the various configurations. Specific data obtained included: (1) incident velocity and temperature, (2) the velocity and temperature aft of the fence (at least 50 feet down wake) and (3) the general turbulence aft of the fence.

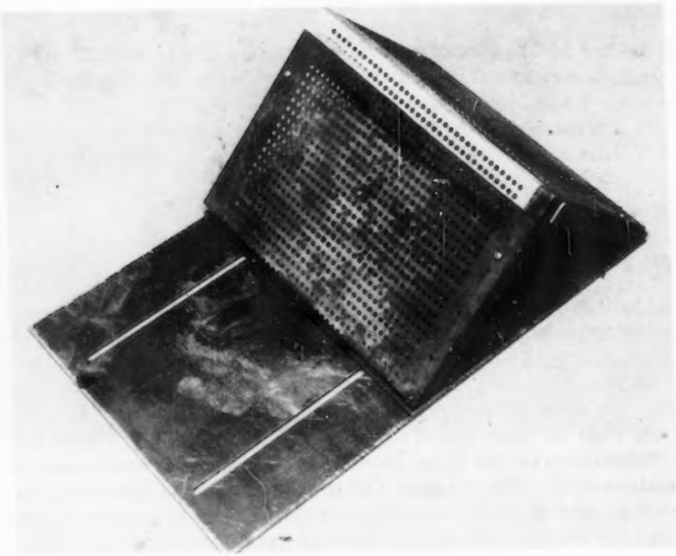


Fig. 16

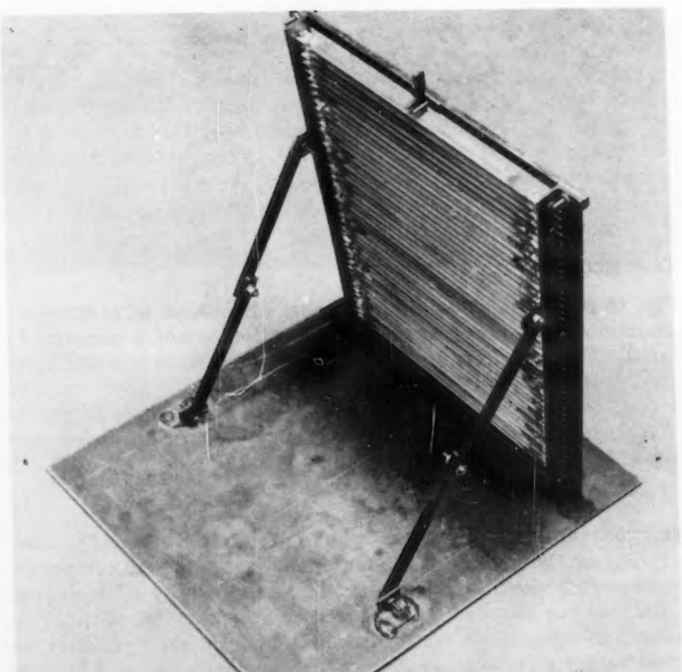


Fig. 17

c. Test Equipment

The test equipment is shown in Fig. 18. The model blast engine burns natural gas and compressed air; its nozzle exit diameter is 2-1/2 inches; an air-gas ratio valve maintains a constant relation of fuel mixture; 35 lbs. of air pressure was used. At low velocities the blast tended to rise in an arc to convection currents. To reduce this to an acceptable minimum an asbestos board trough was placed between the nozzle and the model. This trough also maintained prototype relationships between the size of the jet stream and the distance from the ground. Powdered aluminum was introduced into the blast to produce bright individual sparks so that gas velocities could be measured with the high speed movie camera. A thermocouple grid (not shown in the picture) was used to measure temperatures in the blast.

The movie camera is rated at 1000 to 3000 frames per second. All tests were taken at 1400 frames per second. Four 500 watt spot lights provided normal illumination for photography.

A Schlieren optical system was integrated with the movie equipment, but was independent of it photographically. The 10 inch spherical mirror may be seen behind the test model. A single knife edge, a 90 degree optical prism and an exciter lamp were mounted in a brass sleeve and attached to the lense of the camera. Thus, the deflected wake could be clearly observed or photographed.

Fig. 19 (with a photogenic model) shows the Schlieren effect. The thermocouple grid is not shown in this picture. Human hands were used aft of the fence to detect conditions more than a few degrees above ambient and to assure that no adverse deflections were occurring outside the normal camera range.

d. Number of Tests

Twenty preliminary tests were made for calibration and adjustment, followed by 110 individual model setup tests. Each test was observed and photographed with the Schlieren system, the pattern beyond the camera range was noted, temperatures were recorded and full written notes taken. Trials were also made with low velocities to observe whether significant changes in deflections occurred. At the conclusion of the individual tests several setups were made to observe heat and blast effects at a stabilized heat condition. Each of these tests lasted five minutes.

e. Test Results

The results of the tests are summarized as follows:

(1) The single and double faced flat surface fence spread the gas sideways as well as upward. The deflection was not tangent to the surface but was bent downwake toward the horizontal. This bending was evidently caused by the negative pressure behind the fence. This was not acceptable since the wake would not clear the empennage of adjacent aircraft.

(2) Perforated plate acted in the same way except some of the gas passed through for a prototype distance of from two to five feet downwake.

(3) The steeper the angle of the plates the more pronounced was the bending over of the wake.

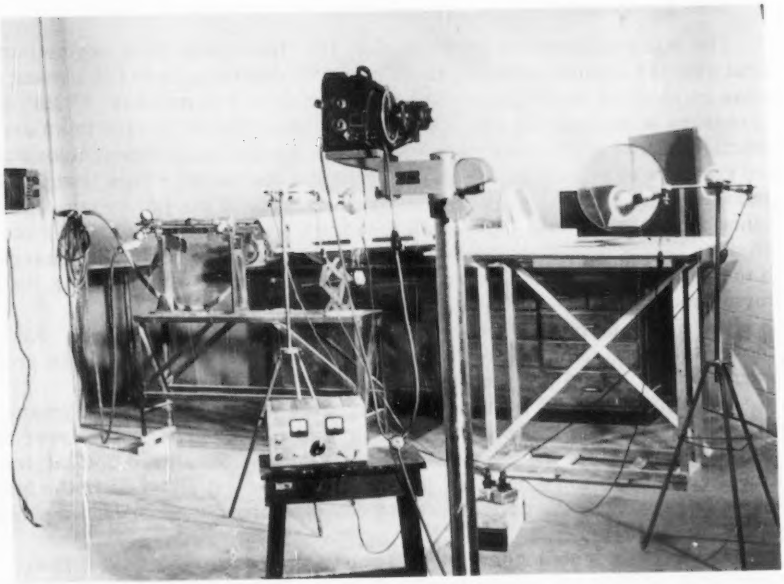


Fig. 18

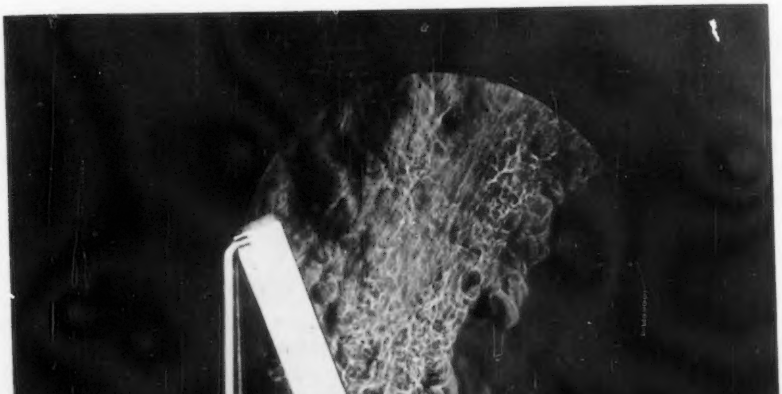


Fig. 19

(4) The louvered models gave a much better deflection. The flat vanes, however, showed the same bending of the wake toward the horizontal as was experienced with the single and double flat surface fences.
(5) The louvered curved vanes caused the wake to exit tangent to the trailing edge of the vane.
(6) The optimum configuration of curved louvered vanes is shown in Fig. 20. Note that the exit edge of the vane is vertical and the leading edge at a 15 degree entry angle to the jet stream. The vanes were spaced apart vertically by 1/3 of the vertical height of the vane. At greater spacing the line of deflection bent downwake toward the horizontal.

f. Test Conclusions

(1) Time did not permit the testing of several parameters that would have been of interest, however, there was enough evidence from the tests conducted to allow the design of prototypes for full scale field testing.
(2) The tests assured that jet exhaust gas at the expected temperatures and velocities can be deflected by any of several fence configurations built of mild steel.
(3) That a properly designed curved vane louvered fence accomplished 90 degree deflections from the base of the fence upward to infinity and
(4) That a segmented or curved louvered fence performs more satisfactorily than the flat plate fence or the flat vane louvered fence.

Prototype Tests

Four full scale prototype fences were built at Castle Air Force Base for testing under field conditions with the blast of the KC 135 and the B-52. The tests were under the supervision of an engineer from the Directorate of Installations, Hq SAC.

a. Test Models

Each prototype was 90 feet long, the length required to accommodate the 4 jet engines on one wing of a B-52. Two fences were built at the end of each of two parking stubs. Since there was still a desire to use the surplus pierced steel planking, one fence was built of this material using the planks as flat louvers. The second fence was built with segmented louvered vanes. The third fence had curved louvered vanes. The fourth fence was a single curved vane approximately 8 feet high made of a 90 degree arc of galvanized corregated metal mounted on a steel frame. With the exception of the last fence mentioned the test fences were approximately 12 feet high and designed to allow maximum adjustability and variations in vane spacing and angle of attack of the leading edge similar to the models tested in the laboratory.

b. Number of Tests

More than 30 test runs were made with varying arrangement of these 4 basic configurations.

c. Scope and Objective of Tests

The scope and objectives of the test were essentially the same as the laboratory tests so that correlations could be obtained. However, the

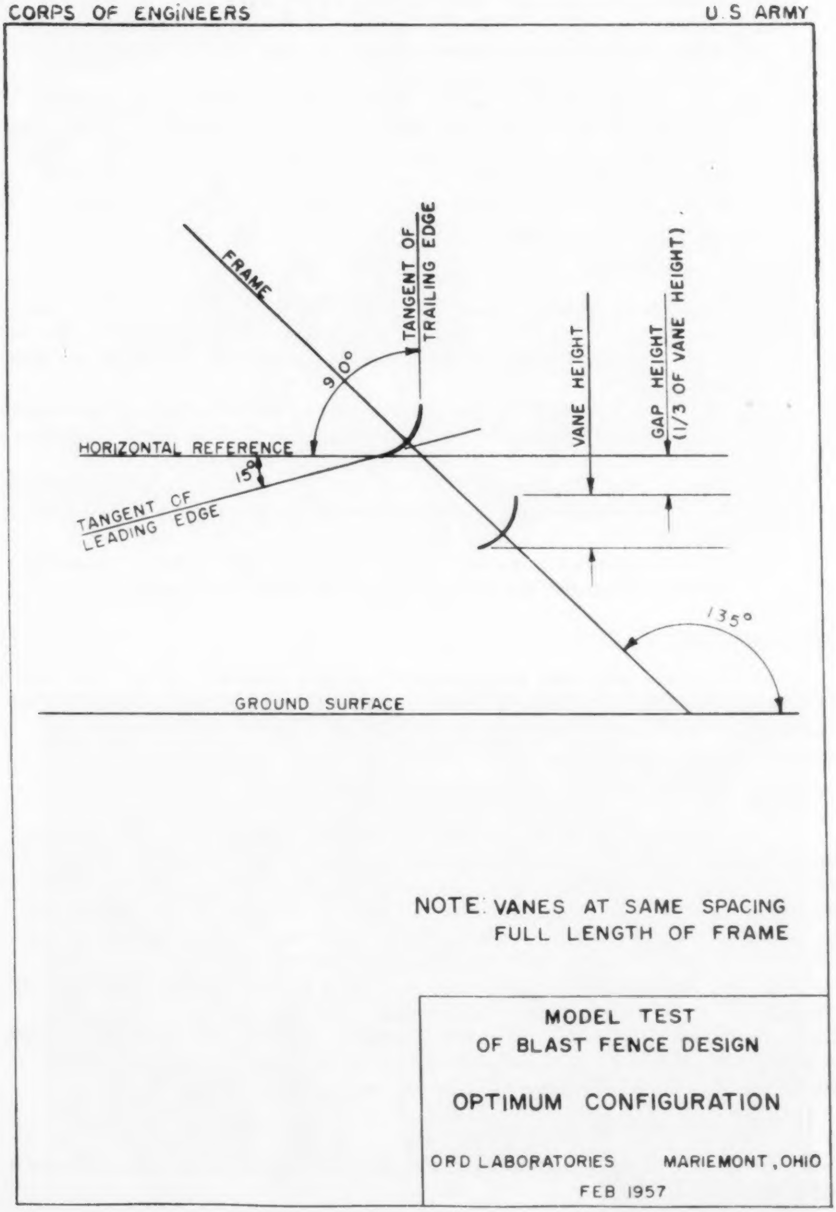

CORPS OF ENGINEERS
U.S ARMY
FRAME
TANGENT OF TRAILING EDGE
90°
VANE HEIGHT
GAP HEIGHT (1/3 OF VANE HEIGHT)
HORIZONTAL REFERENCE
15°
TANGENT OF LEADING EDGE
135°
GROUND SURFACE
NOTE: VANES AT SAME SPACING FULL LENGTH OF FRAME
MODEL TEST
OF BLAST FENCE DESIGN
OPTIMUM CONFIGURATION
ORD LABORATORIES MARIEMONT, OHIO
FEB 1957

Fig. 20

objectives were broadened to include the determination of the actual blast velocity pattern coming against the face of the fence and the recording of the very important data of horizontal and vertical load reactions on one section of each fence.

The fences were fully instrumented with recording devices and also with visual aids, in the form of streamers. Smoke pots were substituted for the Schlieren optical system, to assist in observation and photography.

d. Test Site and Equipment

Fig. 21 shows a general view of one half of the test area. The trailer in the left foreground housed the recording instruments. Smoke pots may be seen in front of the fence. Velocity probes and load cells are mounted on two 10 ft. by 3 in. steel pipes in front of the fence. Other load cells may be seen protruding to the rear of the fence on the concrete pad about a third of the fence length from the close end. Wind measuring sets and streamers are mounted on the six foot poles which are five feet behind the fence and also on the 40 ft. poles which are 25 feet behind the fence. Twelve thermocouples were spotted at various places in front of the fence, on the fence and behind the fence. Sound pressure measurements were taken by a team of men equipped with portable meters who took readings at preselected positions during each test.

Fig. 22 is a close-up of the rear load cells used. Thru the fence may be seen one of the pipes on which the front load cells and the velocity probes are mounted. These probes are probably unique in design. They consisted of 2 SR-4 strain gauges mounted on a machined steel rod and calibrated to read velocities as the rod was deflected by the mass air force. Data was transmitted from the strain gauges and probes through high gain type amplifiers on to a six channel oscillograph recorder.

The question may arise—why measure velocities when engines with known characteristics are being used? Frankly, there existed conflicting data as to what velocity would be encountered at a given distance down wake from a given jet engine. These tests have permitted some observations which have confirmed the findings at MIT, on this subject, which were published in a Meteor Report titled "Momentum and Mass Transfer in Coaxial Gas Jets", dated July 1949. The MIT report gives the following formula for computing the center line velocity of the wake:

$$\frac{U_c}{U_p} = \frac{4}{x/D}$$

U_c = Velocity on the axis at a given X.

U_p = Velocity of jet at X = 0 (at nozzle)

D = Diameter of jet nozzle.

X = Axial distance downstream from jet exit.

The average recordings of these tests correlated very closely with this formula. It should be pointed out further that the extreme limits of the instantaneous velocities making up these averages were as high as 200% and as low as 20% of the average. These maximum and minimum velocities occurred three to six times per second.

Fig. 21

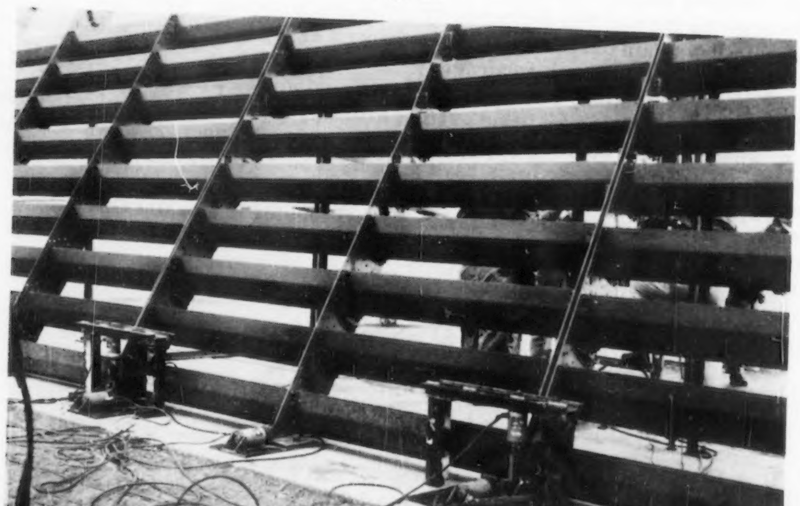


Fig. 22

Before summarizing the results of the deflection test it is desirable to point out the results of the sound measurements aft of the fences. There is a slight shadow effect of sound attenuation immediately behind the fences. However, no fence tested offered sufficient attenuation to allow personnel to work in the area without mandatory ear protection. AFR 160-3 recommends ear protection when the pressure level reaches 85 decibels and makes ear protection mandatory when the pressure level reaches 95 decibels. All readings behind the fence exceeded the 95 decibel level.

e. Summary of Test Results

A summary of the prototype test results follows:

Fig. 23 is a sketch of a fence with louvered flat vanes made of pierced steel plank. This particular arrangement of 19 vanes sloped 10 degrees from vertical gave the best deflection pattern of all variations of pierced steel plank vanes tried.

Fig. 24 shows the typical deflection pattern.

Fig. 25 shows the pierced steel plank vane fence in the optimum configuration. Unfortunately the 5 foot sections of pierced steel plank vane between the uprights vibrated violently and were considered to be structurally inadequate. Also the top of the fence showed a 3 to 4 inch lateral movement. The provision of the necessary framing to eliminate these weaknesses of the vanes was considered economically infeasible. The results of this group of tests correlated well with the laboratory results and with field experience with flat vane fences. Two important similarities were revealed: first, when the vanes are spaced, without at least a double overlap, the blast leaving the trailing edge of the fence is deflected down wake to an unacceptable degree, and second, flat vanes have a tendency to vibrate with resultant structural failure.

Fig. 26 shows a sketch of a fence with segmented louver vanes. This sketch also shows the optimum spacing and arrangement of 9 vanes on 15 inch centers, the vertical height of the vanes on the diagonal spacers being 115 inches.

Fig. 27 shows the typical deflection pattern of this arrangement. Again the laboratory results were very closely correlated. The most important points being; one, that the optimum vertical spacing between vanes is 1/3 of the vertical height of the vane; two, that a segmented vane is more stable structurally than a flat vane; and three, that with the segmented vane the wake leaves the vane approximately tangent to the trailing edge.

Fig. 28 is a sketch of a fence with curved louvered vanes. This fence reacted, for all practical purposes, the same as the segmented louvered vane fence just shown.

Fig. 29 shows a typical deflection pattern.

Fig. 30 shows the multiple curved vane fence, however this picture shows 15 vanes rather than the optimum of 9 vanes as shown in a previous sketch.

Both segmented and curved vanes were tried because there was a question of economics and the ability of local fabricators to furnish curved vanes. A suitable alternate for curved vanes was being sought.

Fig. 31 shows a sketch of the single curved vane fence. It is interesting to note that early tests of this fence with the leading edge bolted in contact with the pavement showed the undesirable characteristics of extreme induced turbulence at each end and behind the fence. Also the deflected wake bent

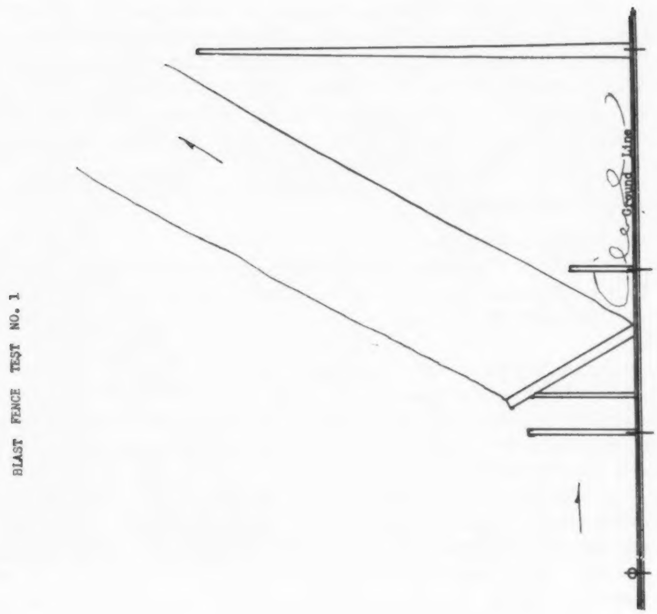

BLAST FENCE TEST NO. 1
40' Pole
Ground Line
Clear
6' Post
Fence
10' post
smoke pot

Fig. 24

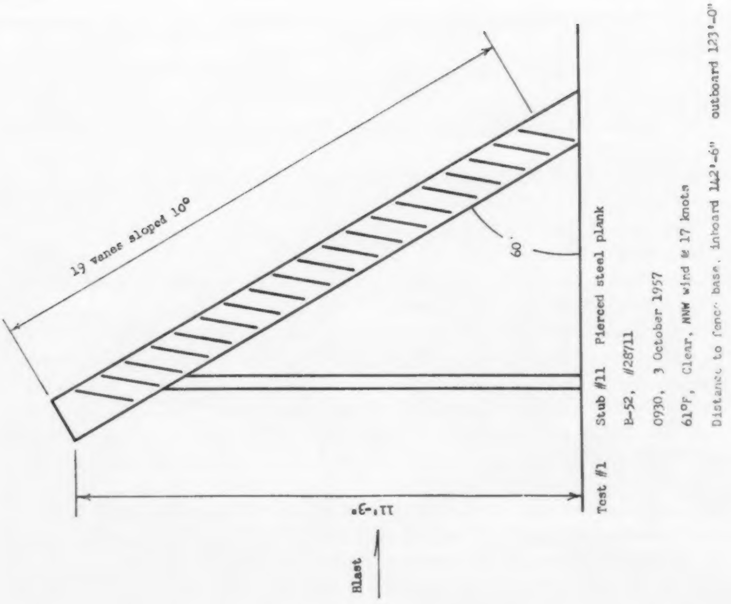

19 vanes sloped 10°
60°
11'-3"
Blast
Test #1 Stub #11 Pierced steel plank
B-52, #28711
0930, 3 October 1957
61°F, Clear, NNW wind @ 17 knots
Distance to fence base, inboard 142'-6" outboard 123'-0"

Fig. 23

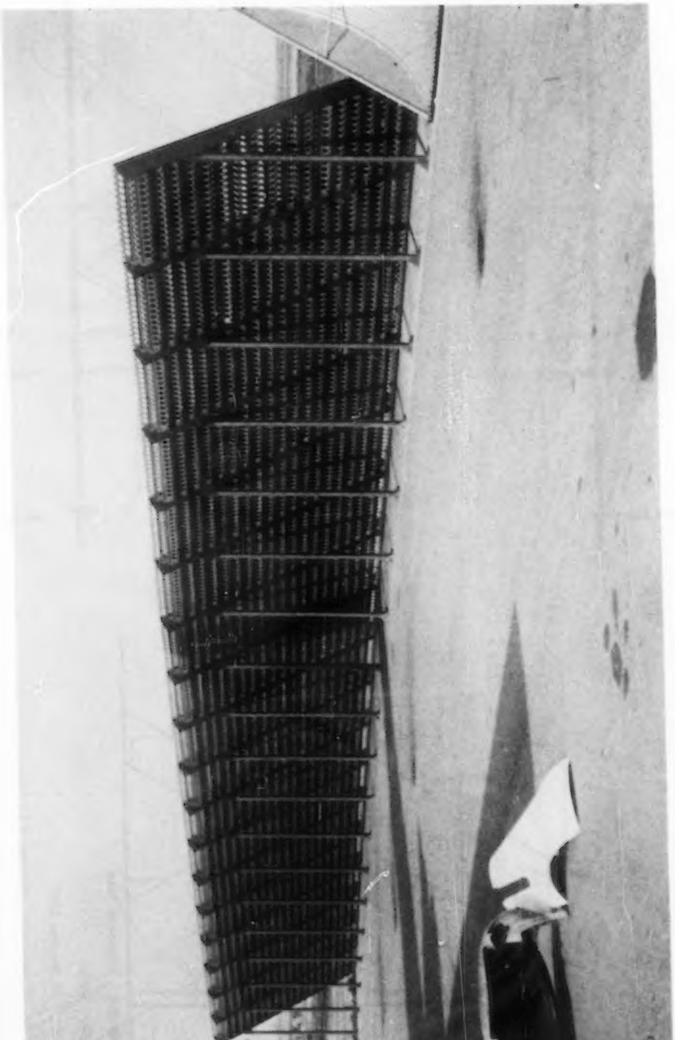
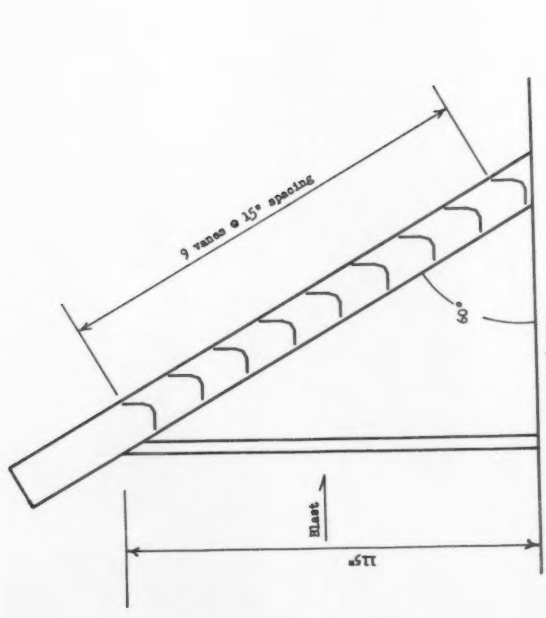


Fig. 25

BLAST FENCE TEST NO. 22



Test #22 Stub #12 Segmented vane

B-52, #2005

1520, 10 October 1957

57°F, Cloudy-Rain, ENE wind @ 10 knots

Distance to fence base, inboard 142'-6" outboard 123'-0"

Fig. 26

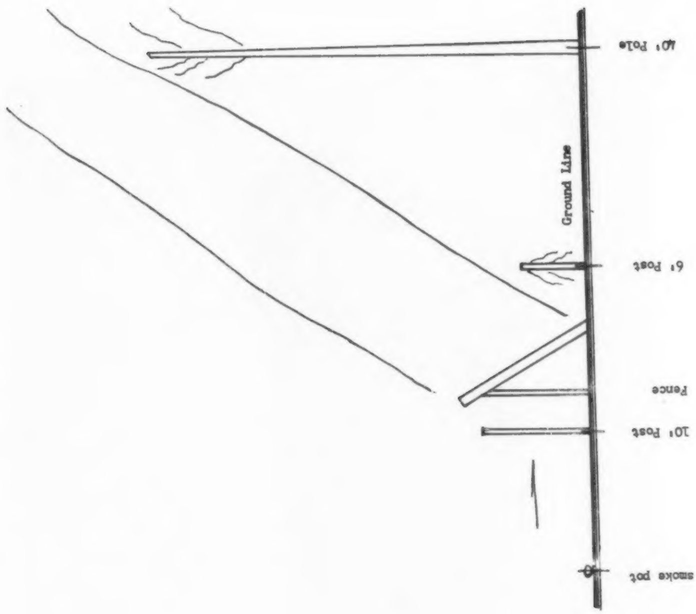
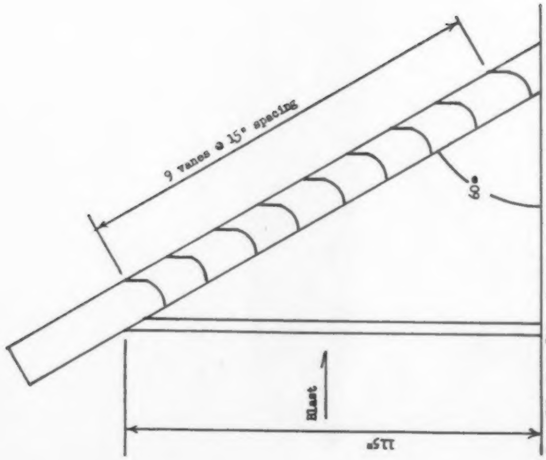


Fig. 27

BLAST FENCE TEST NO. 21



Test #21 Stub #12 Curved vane

B-52, #2005

1440, 10 October 1957

57°F, Cloudy-Rain, ENE wind @ 10 knots

Distance to fence base, inboard 142'-6" outboard 123'-0"

Fig. 28

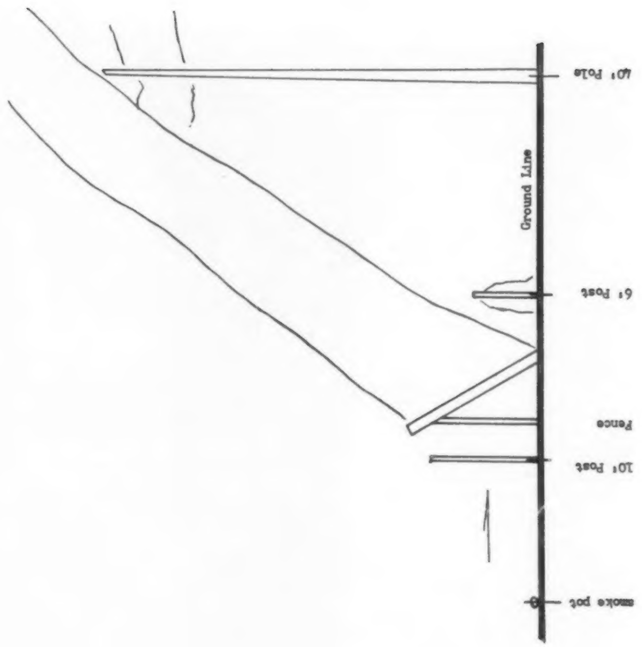


Fig. 29

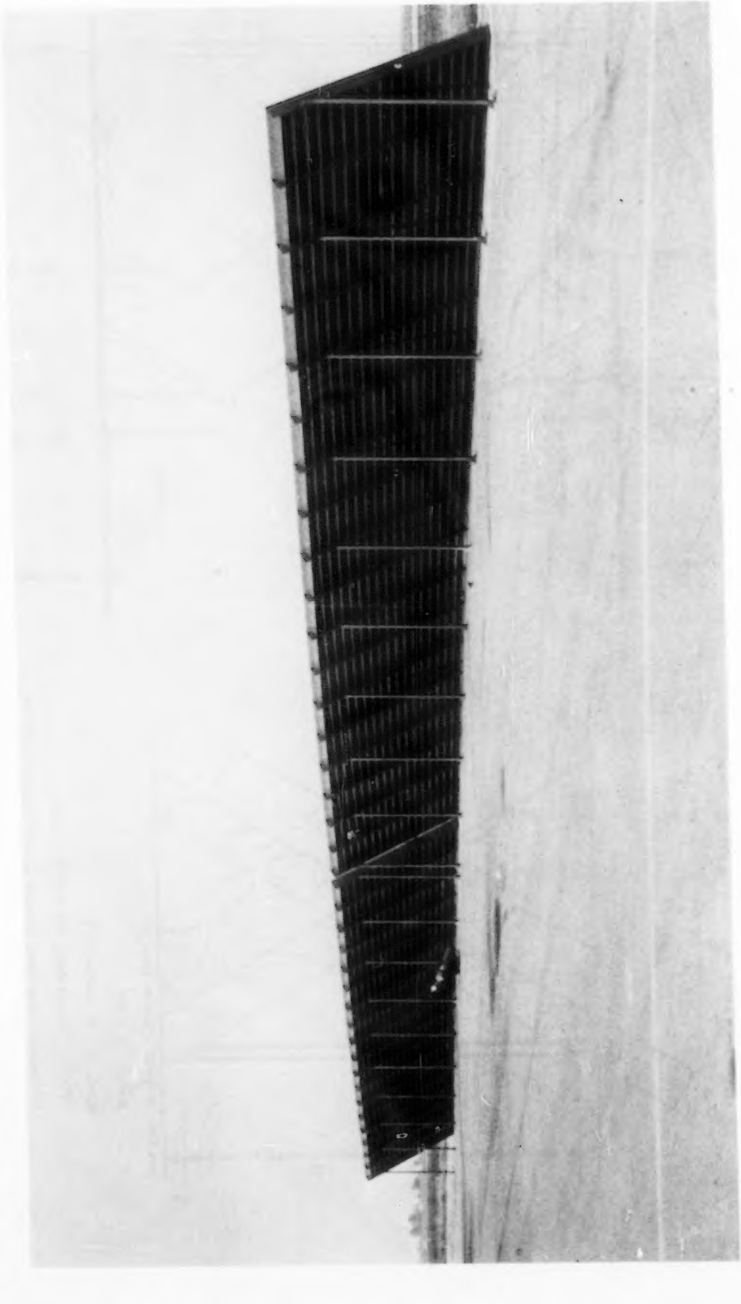
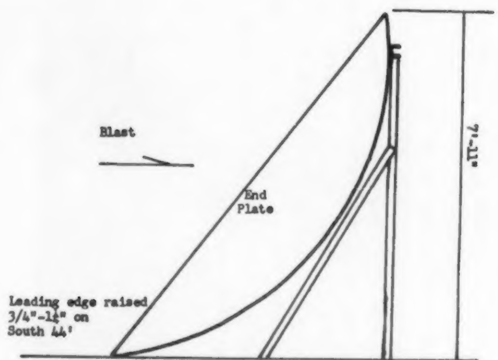


Fig. 30

BLAST FENCE TEST NO. 27



Test #27 Stub #11 Single Vane (corrugated) Lynnco

B-52 #3385

1430 11 October 1957

61°F Cloudy, damp. Calm

Distance to fence base, inboard 142'-6" outboard 123'-0"

Fig. 31

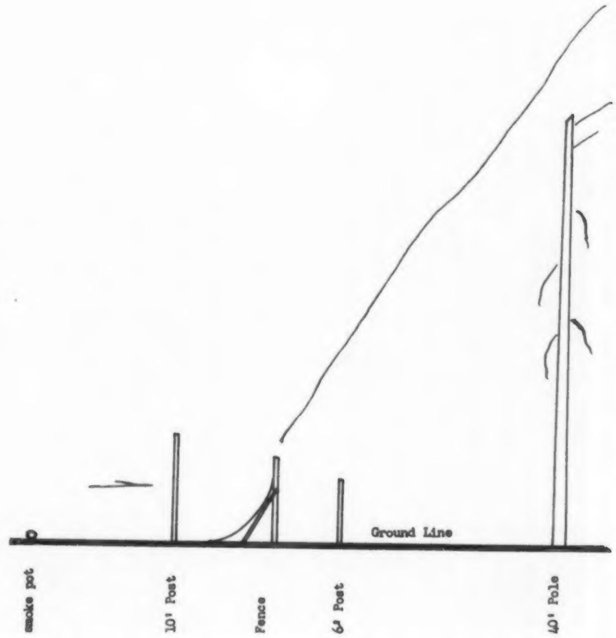


Fig. 32

toward the horizontal on leaving the trailing edge. However, this fence was economical and had other desirable features that warranted further testing. First, an attempt was made to break up the turbulence aft of the fence by leaving vertical spaces between the sheets. This helped but left enough adverse effects to encourage additional attempts. The next effort was to close the openings and raise the toe of the fence to allow a by-pass to reduce the negative pressure behind the fence and help suppress the induced drafts. This appears to be the right approach. By varying the opening under the toe of the fence it was found that the turbulent condition was virtually absent when the toe was raised 1-1/4 to 1-1/2 inches off of the pavement.

Fig. 32 shows the typical deflection pattern with the modified installation.

Fig. 33 shows the experimental single vaned fence. Note that the toe is raised off the apron.

Economics

Prior to these tests the only blast fences used by the Air Force that would meet requirements for close tail to tail parking of B-52s on mass parking aprons were costing close to $100.00 per linear foot installed on existing pavement. The multiple curved vane and single curved vane fences which were proven to meet these B-52 requirements, by this investigational engineering exercise, may be procured for from $30 to $35 per linear foot installed on existing paving.

CONCLUSIONS

1. This investigational engineering project answered the question of "which fence design was best suited and most economical to meet the B-52 requirement on mass parking aprons".
2. There is evidence from the laboratory tests and field use that less expensive fences will suffice for lesser blast protection requirements.
3. Surplus pierced steel plank is not structurally suitable for blast fences subject to blast pressure used in these tests without prohibitive costs for the necessary additional framing support.
4. It is realized that, in these tests, only the needs of a specific requirement have been met. The B-52 requirements will soon be superseded by those generated by the B-58 and again new requirements will be encountered with the advent of the chemically fueled bomber and perhaps in the future be changed again to meet the needs for the plasma jet nuclear powered aircraft.

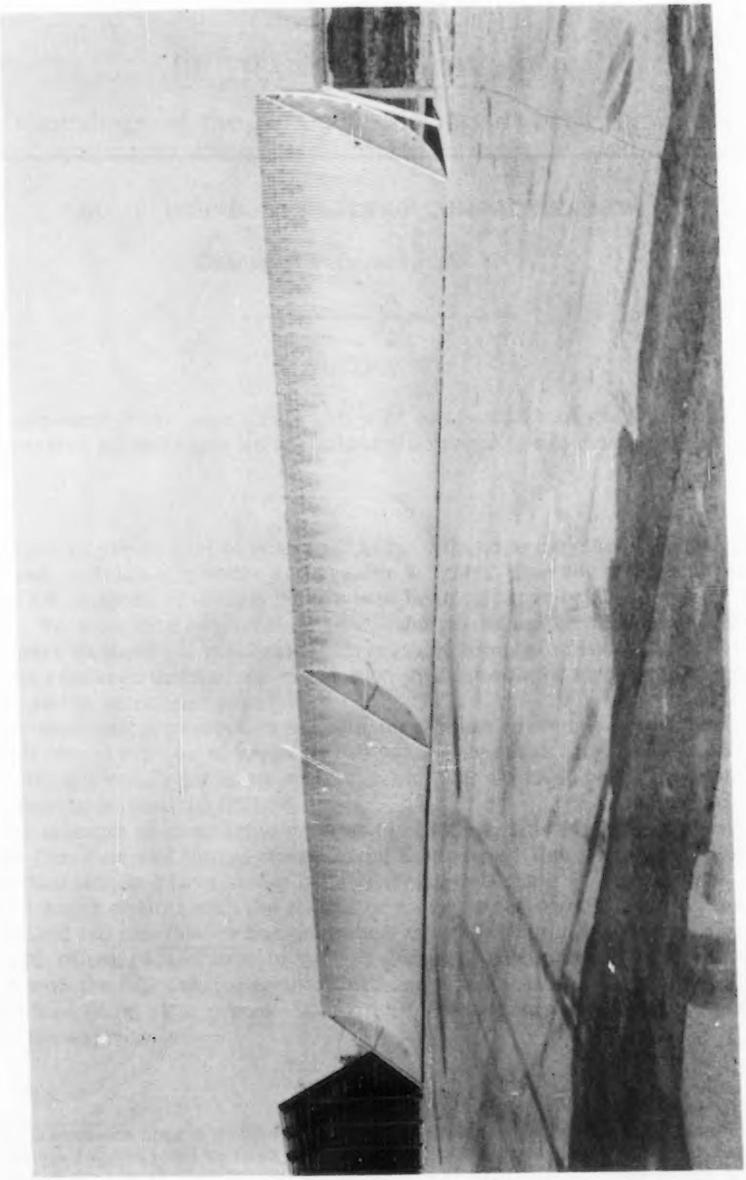


Fig. 33

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COMPRESSIVE STRENGTH OF COMPACTED SNOW

Gunnar S. Pedersen,[1] M. ASCE

ABSTRACT

Tests carried out with 10 cm cubes of compacted snow to determine the compressive strength and its variations with density, are described.

In recent years, airfields and roads built on snow have been used by aircraft and vehicles of greater and greater weights. Thereby a demand has grown for methods of increasing the load bearing capacity of the natural snow cover. To meet this requirement in a technical-scientific manner it has been necessary to study the mechanical strength of compacted snow. Some of the various research institutions working on these problems have been briefly mentioned in an earlier paper.(1)

The mechanical properties of the natural snow cover have been thoroughly studied over a number of years by the Swiss Schneeund Lawinen Forschungsinstitutt, and values for compressive, tensil and shear strength have been published by Haefeli in 1939.(2)

The strength of compacted snow has been studied by Russian scientists and by the Canadian and United States Army Engineers. However, few of the results thus obtained have so far been generally available.

In a paper dealing with the testing of a compacted snow runway on the Greenland Ice cap Bender has published values for compressive and shear strength of compacted snow of various densities.(3) In the same paper he deals with the influence of temperature and age-hardening on the strength of compacted snow. For the relationship between strength and temperature he gives the expression:

Note: Discussion open until June 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1893 is part of the copyrighted Journal of the Air Transport Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. AT 1, January, 1959.

1. Military Dist. Engr., Trondelag Dist., Norway.

$$\log \frac{S_2}{S_1} = 0.16 \log \frac{T_2}{T_1}$$

S_1 = the strength at T_1 °C

S_2 = the strength at T_2 °C

Samset has studied the strength of snow in connection with timber transport with horse and tractors on compacted snow roads.(4) He measured what he terms the breaking strength of snow, by pressing a proctor needle of 2.5 sq.mm into the compacted snow for a distance of 50 mm. Based on a large number of tests, he gives the following formula for the variation of breaking strength with density and snow temperature when the snow consists of well mixed grains of 1.5 - 2.5 mm diameter.

$$bk = +\,2.40 \,.\, t \div 10.91 \,.\, q \,.\, t + 7.8$$

bk = breaking strength in kg/cm^2

t = temperature in °C

q = density in kg/dm^3

Samset points out that the breaking strength values must only be regarded as relative values.

The investigations carried out by the above mentioned scientists and others, show that the strength of compacted snow is influenced by the following factors:

Density
Temperature
Age-hardening
Grain size
Grain bonding
Rate of loading

When in January 1957 the problem of constructing runways on snow for heavy aircraft was taken up in Norway as a preliminary study of the possibilities of air transport to Queen Maud Land, it was found that few quantitative values of the strength of compacted snow were available.

It was therefore decided to carry out a few tests on compacted snow to get a rough idea of its strength as a material for runway construction.

As it was found from the information available that density seemed to be the most important single factor deciding the strength of compacted snow, the tests were so planned that they should indicate the variation of strength with density.

The resources for a scientific research program were not available and therefore the simple expedient of using concrete testing equipment for measuring the compressive strength of 10 cm snow cubes of varying densities was chosen.

The first test serial which was run on 4. Dec. 1957 consisted of only 3 cubes. Newly fallen snow at outdoor temperature ÷ 14°C was brought into a room of + 13°C and compacted in the 10 cm steel forms by means of a concrete cube and a heavy hammer to densities of 0.61 kg/dm^3. The process of compaction took about 40 minutes, whereafter the cubes were left to cool at outdoor temperature for about 45 minutes before testing. Testing was done in

a Mohr & Federhoff compression machine with the pressure plates precooled to ÷ 15°C. The temperature in the testing room was + 18°C.

The test of cube No. 1 failed to give correct results due to insufficient oil supply in the container of the testing machine.

Cube No. 2 was loaded at a average rate of 10 kg/sek. to a total load of 1345 kg without breaking. At this load the cube was deformed to a height of 5.6 cm and a cross section of 11.5 cm x 12.5 cm. A 5 mm wide vertical crack had opened in one side.

Cube No. 3 was loaded at the highest rate the machine could produce to 430 kg. At this load the cube cracked vertically like a concrete cube sometimes does. The reduction on height was 4 mm and the corresponding compression strength 4.3 kg/cm^2.

The results of these first tests seemed so interesting that it was decided to carry on with a new serial of 10 - 20 cubes of varying densities. This test serial was to be run at a high rate of loading to produce a break of the cubes instead of large plastic deformation. In this way it was hoped to find some correlation between compressive strength and density. As the whole test still was very coarsly arranged, and the other factors affecting the strength of compacted snow, were given little consideration, accurate results were by no means expected.

The second test serial of 15 snow cubes was prepared in the open at an outdoor temperature of ÷ 8°C on 10. January 1958. The snow which was medium grained drift snow was compacted in the 10 cm steel forms by means of a wood block and a hammer. To loosen the cubes from the forms, they were brought into a room of + 9°C temperature for about 20 minutes. The density of the cubes was varied from 0.49 - 0.60 kg/dm^3. After weighing, the cubes were left outdoors over night. The next morning the temperature had risen to ÷ 1°C.

Two of the cubes marked No. 1 and No. 9 were tested in the Mohr & Federhoff compression machine which was regulated for a maximum load of 1500 kg and a rate of loading of 3 mm/sek. As in the first test, the compression plates of the machine were precooled to ÷ 15°C. The testing room temperature was + 18°C. It took about 5 minutes to test each cube. Cube No. 1 with density 0.52 broke at 3.43 kg/cm^2. Cube No. 9 with density 0.56 broke at 1.89 kg/cm^2.

The relatively low compressive strengths of these two cubes were accounted to the high snow temperature of ÷ 1°C. As it was of greater interest to obtain information about the compressive strength of snow of lower temperature, the other 13 cubes were left in the freezing room of the laboratory for 48 hours at a temperature of ÷ 15°C.

On 13. January 1958 10 of these cubes were tested with the machine set as before, to max. load 1500 kg and rate of loading 3 mm/sek. All the cubes had brittle colapses at loads shown in Table I.

A third test serial of 6 cubes, marked No. 16 - 21, was prepared on the 13. January 1958 and tested the same day. The outdoor temperature had now risen to 0°C. The cubes were prepared in the same manner as for the previous serial, then stored outdoors for 1-1/2 hours whereafter they were kept in the freezing room of the laboratory at ÷ 15°C for about 1 hour. During the testing the compression machine was set as before to max. load 1500 kg and rate of loading 3 mm/sek. All six cubes showed brittle colapses at loads shown in Table II.

Table I.

2. Test Serial. Temperature ÷15°C Rate of Loading 3 mm/sek.

Cube No.	Density	Breaking Load in kg.
2	0.51	580
3	0.49	566
4	0.53	487
5	0.53	487
6	0.55	438
7	0.55	488
8	0.56	335
10	0.57	532
11	0.58	703
12	0.60	746

Table II.

3. Test Serial. Temperature ÷15°C Rate of Loading 3 mm/sek.

Cube No.	Density	Breaking Load in kg.
16	0.59	1082
17	0.61	1110
18	0.62	1096
19	0.59	568
20	0.60	838
21	0.62	1406

The results of the tests in the second and third serial are plotted in the diagram of Fig. I.

1. The average compressive strength of the 10 cubes in the 2. test serial with densities 0.49 - 0.60 kg/dm^3 and temperature ÷ 15^{o}C, at a rate of loading of 3 mm/sek. is 5.4 kg/cm^2.
2. The average compressive strength of the 6 cubes in the 3. test serial with densities 0.59 - 0.62 kg/dm^3 and temperature ÷ 15^{o}C, at a rate of loading of 3 mm/sek. is 10.2 kg/cm^2.
3. The general trend of the results, is an increase in compressive strength with increasing density.
4. The increase in compressive strength with density is greater in the 3. test serial than in the 2. test serial. This may be due to the 3. test serial being compacted at a higher temperature.

To study the compressive strength of snow under a less rapidly increasing load, three cubes from the second test serial were tested with rates of loading 0.25 - 0.50 mm/sek. For these cubes the deformations were also registered as shown in the diagrams of Fig. 2 and in Table III.

Cubes No. 13 and 14 were loaded to 1500 kg without breaking. For cube No. 15 the maximum load of the compression machine was set to 3000 kg. At this load the cube still did not break.

Under the comparative slowly increasing loads on these 3 cubes, the snow structure got time to readjust itself without breaking. As seen from the diagrams in Fig. 2 and Table III the deformations are large compared with the dimensions of the cube.

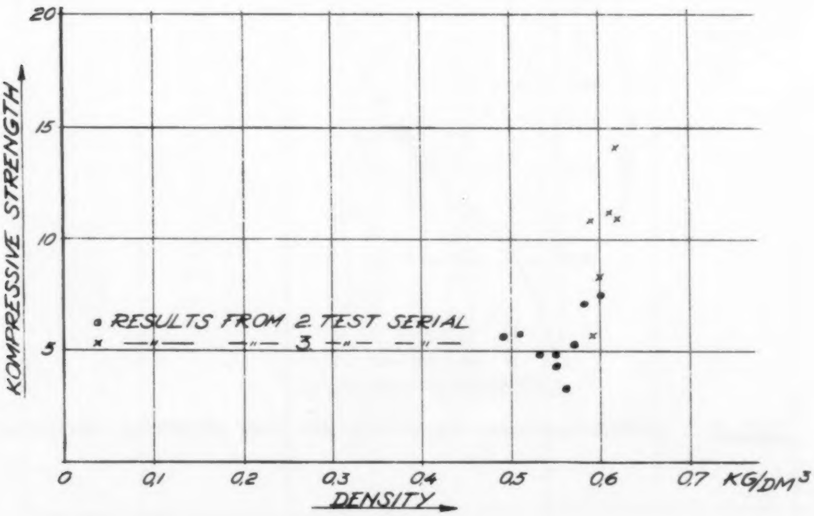

FIG. 1 COMPRESSIVE STRENGTH VERSUS DENSITY

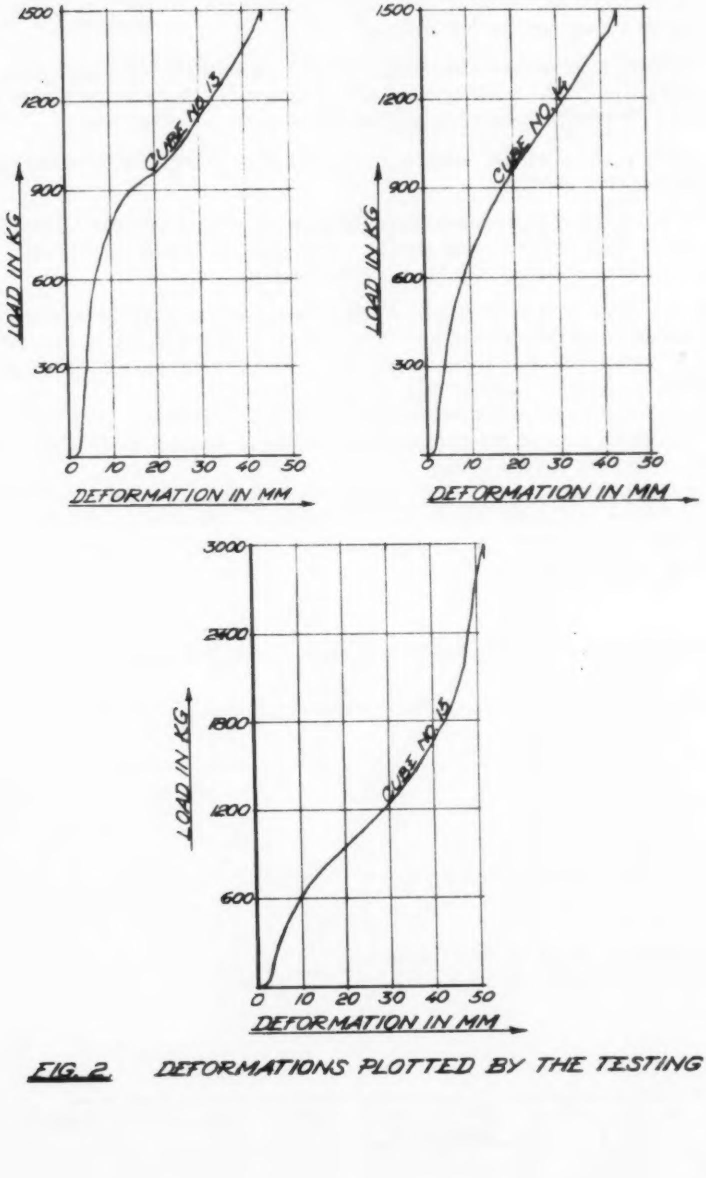

FIG. 2. DEFORMATIONS PLOTTED BY THE TESTING MACHINE

Table III.

Deformations of Test Cubes No. 13, No. 14 and No. 15.

Testing temperature ÷ 15°C.

Test Cube No.13 Density 0.57 kg/dm^3 Rate of loading 0.25 mm/sek. Max. load 1500 kg.		Test Cube No.14 Density 0.57 kg/dm^3 Rate of loading 0.25 mm/sek. Max. load 1500 kg.		Test Cube No.15 Density 0.55 kg/dm^3 Rate of loading 0.35 - 50 mm/sek. Max. load 3000 kg.	
Load kg.	Def. mm	Load kg.	Def. mm	Load kg.	Def. mm.
500	6.0	130	2	150	2
650	8.5	265	3	345	4
720	9.5	360	4	475	6
780	10.5	435	5	570	8
815	11.5	485	6	650	10
850	12.5	530	7	740	12
870	13.5	535	8	810	14
895	14.5	620	9	865	16
906	15.5	660	10	925	18
916	16.5	700	11	980	20
926	17.5	732	12	1030	22
934	18.5	768	13	1090	24
942	19.5	800	14	1150	26
952	20.5	822	15	1200	28
962	21.5	833	16	1290	30
975	22.5	885	17	1320	32
988	23.5	906	18	1400	34
1012	24.5	930	19	1480	36
1030	25.5	950	20	1560	38
1053	26.5	974	21	1650	40
1075	27.5	996	22	1760	42
1120	28.5	1015	23	1860	44
1125	29.5	1036	24	2040	46
1160	30.5	1055	25	2220	48
1180	31.5	1072	26	2680	50
1200	32.5	1092	27	2975	52
1225	33.5	1110	28		
1248	34.5	1130	29		
1274	35.5	1148	30		
1300	36.5	1174	31		
1322	37.5	1200	32		
1345	38.5	1223	33		
1366	39.5	1248	34		
1390	40.5	1274	35		
1406	41.5	1300	36		
1430	42.5	1320	37		
1465	43.5	1343	38		
1500	44.5	1360	39		
		1372	40		
		1378	41		
		1410	42		
		1454	43		
		1500	43.5		

During the testing of cubes No. 13, 14 and 15 a gradual change of the colour of the snow from white to grey could be observed. The change of colour started at the compression plates at the top and bottom of the cubes and grew towards the middle, where the grey colour eventually meet. The change of colour seemed to indicate a change of the snow into a kind of ice. After the cubes were compressed to the maximum load of the machine respectively 1500 and 3000 kg, the cubes which by now were reduced to half the original height and with a corresponding increase in cross section had a considerable resemblance to ice.

CONCLUSIONS

The aims of the tests of the compressive strength of snow were:

a) To get a rough idea of the strength of snow as a material for runway construction.

b) To obtain an indication of the variation of strength with density.

From the tests it can be concluded that snow compacted under favourable conditions to a density of about 0.60 kg/dm^3 may obtain an average compressive strength of 10 kg/cm^2 at a temperature of ÷ 15°C when loaded at a rate of 3 mm/sek.

The tests also indicate an increase in strength with increasing density.

The tests further showed that when compressed at a lower rate of loading of 0.25 - 0.50 mm/sek., the snow cubes change into a kind of ice under large deformations and increasing strength.

The preparation of the test cubes clearly demonstrated the difficulties of compacting dry snow at temperatures of ÷ 14°C.

The results of these tests are not unexpected, and because the influences of age-hardening, grain size and grain bonding were purposely left out of the picture, they can not be considered very accurate. However, the tests have demonstrated that it is possible with ordinary concrete testing equipment, to obtain numerical data of the compressive strength of compacted snow. With such data in his hand, the civil engineer can regard snow as a construction material and not only as a white medium for winter sports and snow clearing equipment.

True enough, as a construction material, snow has great limitations, but in low temperature regions it may also have considerable possibilities.

ACKNOWLEDGMENTS

Jarle Berg and Magne Midttun, Civil Engineers, prepared the test cubes. Magne Midttun also conducted the compression tests and wrote the preliminary reports on which this paper is based.

The Material Testing Laboratory of The Technical University of Norway, kindly permitted the tests to be carried out on its premises and with assistance of the laboratory staff.

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CONTENTS

DISCUSSION

A WATER-BORNE RUNWAY[a]

Discussions by W. K. Laing, G. S. Cooper and Morris E. Adams

W. K. LAING.[1]—The suggestions in this paper constitute a completely novel approach to the solution of a problem which has been facing airport constructors for very many years, namely, how to construct a pavement of adequate strength on a formation whose bearing capacity is poor.

On page 13 Mr. Williams has given some indication of the additional cost involved in the provision of water-bags for a runway 2,000 yards long, but in arriving at his figure of £200,000 it seems to me that he has not given sufficient consideration to the additional cost which would be involved as a result of the complication of the contractors' work in constructing a runway of the type he proposes.

There are three main ways in which this complication comes about—

(1) The handling of the bags themselves: Are these to be filled prior to placing in position on the formation? If so, ways would have to be found for loading the filled bags on to trucks at a central filling point and later unloading them at the appropriate point on the runway. Presuming that the bags are to be 6" in depth, each of them would weigh approximately 6 short tons when filled with water: so causing wellnigh insuperable difficulties in handling. On the other hand, if the bags are to be filled after being placed in position on the formation, loading each of them with an accurately weighed amount of water and the sealing of the filling orifice will call for a very close control by the site staff.

(2) Difficulty of concrete placing: In order to achieve adequate strength in the concrete of the pavement the whole of each slab must be of the same thickness, but in view of the flexible nature of the water-bags when the first batch of concrete is placed in a particular bay, deflection of the bag will occur and, as a result, the thickness of the slab will vary continuously, depending on the sequence in which it is placed in the bay, and no amount of work with spreading and finishing equipment will rectify this variation.

Although Mr. Williams does not make any mention of it it may be that he has in mind to use precast slabs. In this case the handling of concrete slabs 20' x 20' and some 6" or 9" in thickness will involve the use of very complicated and specialised equipment which is hardly likely to be sufficiently mobile to be readily used in airfield construction.

(3) Disruption of placing sequence: The present high rate of airfield construction has been achieved largely as the result of the use of

a. Proc. Paper 1658, June, 1958, by D. Williams.

1. Chmn., John Laing and Son, Ltd., London, England.

continuously operating spreading and finishing machines in conjunction with large-size concrete mixers of the paver type. With the system suggested by the author this continuous sequence of operations could not be achieved and each bay would have to be dealt with individually, so slowing down the rate of construction tremendously.

As can be imagined, each of these reasons would cause the cost of airfields constructed by the water-borne system to be very much more expensive than those constructed by what might be termed traditional methods, and it therefore seems that we are unlikely to see the author's suggestion being put into practice.

G. S. COOPER.[1]—The paper provides absorbing reading and, at first sight, seems to offer a new approach to a design problem which has, so far, only been solved by traditional methods. On closer investigation, however, it seems unlikely that the proposals could ever be used in practice, and they provide no more than an interesting theoretical exercise.

The engineer, faced with the design of a concrete (or "rigid") airfield pavement, advances through a series of broad assumptions to a suitable construction detail. The assumptions fall under three main heads as follows:

(a) Those related to the use to which the airfield is to be put; maximum loadings, tire pressures, under-carriage geometry, frequency of loading, etc.
(b) Those related to the pavement slab; the physical properties of the concrete, load transfer, and the design method as a whole.
(c) Those related to the soil on which the pavement is built; its bearing value, and variation of the bearing value over the area to be paved.

In attempting to define the loading for the airfield he is to design, the engineer usually finds it is impossible to obtain really firm data. If he does obtain some criteria, it is likely that, by the time the airfield is built and commissioned, the loading of the aircraft for which it was designed has increased and the under-carriage layout altered. Accordingly, he tends to make his own arbitrary estimate of the ultimate loading and from it to derive an equivalent single wheel load on which to base his design. This figure, not unnaturally, tends to err on the side of safety; in general these inspired guesses turn out to be surprisingly accurate.

In the design of the pavement slab itself, most engineers use the Westergaard method. This has proved reasonably valid but requires broad assumptions on several factors concerning the behavior of the slab, and the properties of the concrete. If load transfer devices are used, further arbitrary assessment has to be made of their efficiency.

Regarding the soil itself, the engineer is faced with a material having extremely elusive properties. The Westergaard formula assumes that the supporting base behaves as a truly elastic medium, and incorporates a constant for the value of the elasticity. Unfortunately, no soil is truly elastic, nor does it recover fully after loading. Also, such elasticity as it does possess may vary considerably over the pavement area. The selection of the figure for soil characteristics for application in the Westergaard formula must involve

1. Chf. Eng. (Works), Headquarters, Bomber Command, RAF, High Wycombe, Buchs, England.

some guesswork, but it is fortunately the case that variation of the soil characteristics constant over a wide range has a relatively small effect on the design thickness of the concrete paving slab.

With so many variables and arbitrary values to consider, the design of a concrete runway is an art rather than a science, and the engineer tends to rely more on his experience than on his theoretical calculations. The waterbag proposals only resolve one set of values, i.e. those related to the supporting soil. This support, which is probably good and bad in patches over the area of a proposed pavement, is transformed into something with uniform predictable behavior. The type of behavior afforded by a water-inflated bag is, however, not one which is particularly welcome to the engineer.

For construction on the surface afforded by the waterbag, the author rightly stipulates a flexible slab. Clearly prestressed concrete is the most suitable material, as he suggests. The most ardent supporters of this material for pavements, however, claim that it is ideal for construction on just the type of subgrade on which the author proposes the waterbags.

Assuming that a runway is available constructed by the waterbag method, two questions arise:

(a) A uniformly level site is seldom to be found. What happens to the waterbags on a slope? They have no rigidity, and it would not be practicable to stiffen them while retaining flexibility. On a sloping site, horizontal shear from the weight of the surfacing medium would be considerable. Even on a level site, shear forces of some magnitude would be introduced when a heavy aircraft is braked.

(b) Certain criteria are laid down for maximum gradients on airfield pavements. The normal figure is 1 in 100. Although a maximum deflection of 1/2% is claimed on page 13, the author mentions, on page 25, a "comparatively small" deflection of one inch to full scale from the model test. This would be 10' distant from the level point at the center of the panel, giving an upward gradient of 1 in 120 towards it.

With the under-carriage travelling nearer the edge of each panel, the deflection would be somewhat greater and the gradient would increase. On a sloping site, or with panels smaller than 20' square, gradients would be quite unacceptably steeper than 1 in 100. Further, beyond the mid point of each panel, the slope would be reversed. An aircraft moving on the pavement would run over a series of undulations, which would produce unpleasant vibratory effects.

An important practical point is not mentioned by the author. Modern aircraft pavements are riddled with ducts required for sundry purposes such as airfield lighting, power supplies, telephone land-lines and fuel distribution pipes. If these can be incorporated in the subsoil before the pavements are laid, so much the better; but it often happens that the pavements have to be cut open to permit ducts to be laid, or to effect repairs, after completion. This task would be extremely difficult with the type of construction envisaged. The problem also applies to prestressed concrete pavements even without the complication of the waterbags.

It seems unlikely that the proposals could have any value in the military field. The essence of rapid construction is transportability and ease of handling. To avoid excessive gradients and limit the undulating effect, panels would have to be at least 20' in size and of considerable weight; they would hardly be manageable. The waterbags themselves would introduce a transportation problem. Above all, a substantial quantity of water is involved. On a

runway 2,000 yds. x 50 yds., with waterbags 6" thick, some 2-1/2 million gallons, weighing over 10,000 tons, would be required.

The author suggests, on page 4, that bomb damage could be easily repaired. This is difficult to reconcile with the need for continuity inherent in prestressed concrete and in the load transfer device proposed. Also, any damage to the pavements would result in the waterbags bursting and so drenching the supporting soil; this could only have the effect of reducing its bearing qualities yet further.

Lastly, as the author states on page 13, there is little to commend the proposal on the grounds of economics. Even at the lower figure of £60 for a 20' square slab, the cost of the waterbags alone would be 27/- per square yard. For this price some 12" of concrete could be built which, under the precast or other slabs providing the final pavement surface, would probably be sufficient to meet the worst soil conditions on which an engineer would be prepared to consider construction of an airfield.

Summarising, the author's proposals seem unlikely to be of practical value to the engineer. They do not appear to meet his basic requirements for economy, ease of construction, good riding surface and simplicity of repair. They do, however, provide an interesting and stimulating theoretical exercise which may give rise to further ideas towards discovering a practical breakaway from the conventional methods of pavement design, and the author is to be congratulated on his paper for this reason.

MORRIS E. ADAMS.[1]—This paper presents a most novel and attractive idea but its whole success depends on the water bags. These look a little frail, but if abrasive effects are prevented, no doubt they should have a good life. As in practice runways may have a longitudinal gradient of up to 1 in 100, the braking effort of an aircraft landing downhill would tend toward a shearing action on the bags and this would have to be watched. Another practical point that springs to mind is that the very greatest care would be required when placing the precast slabs on the bags, to see that they landed absolutely flat. To land on one edge, or worse still on a corner, would almost certainly puncture the bag.

With the hydraulic pressure in the bags causing, as it does, an evenly distributed load on the underside of the slab, the maximum bending moment developed would be greater than that obtained by having the intensity of loading a maximum under the wheel and diminishing across the span. This might call for a heavier slab.

The experimental model is very interesting and the results obtained illuminating. It is noted, however, that the joints between the slabs were formed by tongues of 20 S.W.G. metal. It is felt that this may have acted to some extent as a hinge and could not give the same continuity as post tensioning wires. In this case, in a full scale experiment, the deflections might well be slightly different.

The method of post tensioning given by Morice and Cooley is not entirely clear and rather more information on this would be an advantage. The suggestion that post tensioning might be relaxed to allow the removal of a slab for repair work would involve leaving the ducts unfilled by grout. It is feared

1. Civil Eng.-in-Chief Admiralty, Pinner, Middlesex, England.

this would cause them to be very wet with consequent heavy corrosion of the post tensioning wires.

In brief, this novel idea might be of value in very bad ground but unless the ground was very bad, normal construction methods would probably be more economical. A full scale experimental area would undoubtedly add greatly to knowledge of the system.

AIRPORT APPROACH, RUNWAY AND TAXIWAY LIGHTING SYSTEMS[a]

Discussion by J. F. Newbery

J. F. NEWBERY.[1]—This paper has been read with considerable interest. The historical background and developments leading up to the present lighting systems should be particularly useful in enabling new workers in the field of aerodrome lighting to profit from the experience of the past. The author may be interested to learn of some of the developments in England. They are not fundamental but are rather designed to improve existing facilities.

Angle of Approach Indicators

The new type of angle of approach indicator, described in Part IV-83 of the Report of the 6th Session of AGA Division of ICAO, is now undergoing tests at Blackbushe Airport. This is a two-colour model sponsored by Mr. Calvert of Farnborough which gives a red signal to aircraft undershooting and a white signal at other times. By installing two indicators some distance apart along the runway an approach angle can be indicated. It is a simple apparatus with no lenses or moving parts and has a range of several miles even in full daylight. The older tri-coloured indicator mentioned in this paper is back with the manufacturers for redesign and its future is uncertain.

Runway Lights

Since World War II beamed lights have been used to produce the intensity required from runway lights. In recent years, as the use of these fittings has been extended to smaller aerodromes there has been a demand for some light to be visible from the circuit. It seems impossible to combine the requirements in one fitting and current practice is to install duplicate high intensity beamed and low intensity omni-directional lights. The intensities of all lights have to be carefully controlled so as to ensure that approach and runway lighting as a whole present a properly matched system and to avoid creating dazzle.

Narrow Gauge Lighting

The installation at Gatwick has now been in operation for more than three months and is liked by pilots. The real test however will not come until the fog season starts in October. The dimensions were agreed upon as a result of the Cyclorama tests referred to in the paper; there are four fittings in each row with 75 ft. between rows across the runway and 250 ft. along the runway.

a. Proc. Paper 1659, June, 1958, by C. Edward Walter and Vincent J. Roggeven.

1. Ministry of Transport and Civil Aviation, London, England.

The system extends 3000 ft. from each threshold. Green taxiway lights extend from the runway center-line into each fast turn-off to join the main system of center-line taxiway lighting. They enable pilots to make full use of the fast turn-offs and, quite fortuitously, provide a degree of the center-line continuation beyond the narrow gauge lights as discussed in the paper.

Taxiway Lighting

It is noted that the author considers that more efficient lights may permit the use of blue fittings on both sides of the taxiway. English experience, even with relatively bright blue lights is, that there tends to be confusion between the edges on sharp turns, where one row is seen across the other row. For this reason two colours have been adopted where the taxiway winds.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY 7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

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JANUARY: 1494(EM1), 1495(EM1), 1496(EM1), 1497(IR1), 1498(IR1), 1499(IR1), 1500(IR1), 1501(IR1), 1502 (IR1), 1503(IR1), 1504(IR1), 1505(IR1), 1506(IR1), 1507(IR1), 1508(ST1), 1509(ST1), 1510(ST1), 1511(ST1), 1512(ST1), 1513(WW1), 1514(WW1), 1515(WW1), 1516(WW1), 1517(WW1), 1518(WW1), 1519(ST1), 1520 (EM1)[c], 1521(IR1)[c], 1522(ST1)[c], 1523(WW1)[c], 1524(HW1), 1525(HW1), 1526(HW1)[c], 1527(HW1).

FEBRUARY: 1528(HY1), 1529(PO1), 1530(HY1), 1531(HY1), 1532(HY1), 1533(SA1), 1534(SA1), 1535(SM1), 1536(SM1), 1537(SM1), 1538(PO1)[c], 1539(SA1), 1540(SA1), 1541(SA1), 1542(SA1), 1543(SA1), 1544(SM1), 1545(SM1), 1546(SM1), 1547(SM1), 1548(SM1), 1549(SM1), 1550(SM1), 1551(SM1), 1552(SM1), 1553(PO1), 1554(PO1), 1555(PO1), 1556(PO1), 1557(SA1)[c], 1558(HY1)[c], 1559(SM1)[c]

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APRIL: 1580(EM2), 1581(EM2), 1582(HY2), 1583(HY2), 1584(HY2), 1585(HY2), 1586(HY2), 1587(HY2), 1588 (HY2), 1589(IR2), 1590(IR2), 1591(IR2), 1592(SA2), 1593(SU1), 1594(SU1), 1595(SU1), 1596(EM2), 1597(PO2), 1598(PO2), 1599(PO2), 1600(PO2), 1601(PO2), 1602(PO2), 1603(HY2), 1604(EM2), 1605(SU1)[c], 1606(SA2), 1607(SA2), 1608(SA2), 1609(SA2), 1610(SA2), 1611(SA2), 1612(SA2), 1613(SA2), 1614(SA2)[c], 1615(IR2)[c], 1616 (HY2)[c], 1617(SU1), 1618(PO2)[c], 1619(EM2)[c], 1620(CP1).

MAY: 1621(HW2), 1622(HW2), 1623(HW2), 1624(HW2), 1625(HW2), 1626(HW2), 1627(HW2), 1628(HW2), 1629 (ST3), 1630(ST3), 1631(ST3), 1632(ST3), 1633(ST3), 1634(ST3), 1635(ST3), 1636(ST3), 1637(ST3), 1638(ST3), 1639(WW3), 1640(WW3), 1641(WW3), 1642(WW3), 1643(WW3), 1644(WW3), 1645(SM2), 1646(SM2), 1647 (SM2), 1648(SM2), 1649(SM2), 1650(SM2), 1651(HW2), 1652(HW2)[c], 1653(WW3)[c], 1654(SM2), 1655(SM2), 1656(ST3)[c], 1657(SM2)[c].

JUNE: 1658(AT1), 1659(AT1), 1660(HY3), 1661(HY3), 1662(HY3), 1663(HY3), 1664(HY3), 1665(SA3), 1666 (PL2), 1667(PL2), 1668(PL2), 1669(AT1), 1670(PO3), 1671(PO3), 1672(PO3), 1673(PL2), 1674(PL2), 1675 (PO3), 1676(PO3), 1677(SA3), 1678(SA3), 1679(SA3), 1680(SA3), 1681(SA3), 1682(SA3), 1683(PO3), 1684 (HY3), 1685(SA3), 1686(SA3), 1687(PO3), 1688(SA3)[c], 1689(PO3)[c], 1690(HY3)[c], 1691(PL2)[c].

JULY: 1692(EM3), 1693(EM3), 1694(ST4), 1695(ST4), 1696(ST4), 1697(SU2), 1698(SU2), 1699(SU2), 1700(SU2), 1701(SA4), 1702(SA4), 1703(SA4), 1704(SA4), 1705(SA4), 1706(EM3), 1707(ST4), 1708(ST4), 1709(ST4), 1710 (ST4), 1711(ST4), 1712(ST4), 1713(SU2), 1714(SA4), 1715(SA4), 1716(SU2), 1717(SA4), 1718(EM3), 1719 (EM3), 1720(SU2), 1721(ST4)[c], 1722(ST4), 1723(ST4), 1724(EM3)[c].

AUGUST: 1725(HY4), 1726(HY4), 1727(SM3), 1728(SM3), 1729(SM3), 1730(SM3), 1731(SM3), 1732(SM3), 1733 (PO4), 1734(PO4), 1735(PO4), 1736(PO4), 1737(PO4), 1738(PO4), 1739(PO4), 1740(PO4), 1741(PO4), 1742 (PO4), 1743(PO4), 1744(PO4), 1745(PO4), 1746(PO4), 1747(PO4), 1748(PO4), 1749(PO4).

SEPTEMBER: 1750(IR3), 1751(IR3), 1752(IR3), 1753(IR3), 1754(IR3), 1755(ST5), 1756(ST5), 1757(ST5), 1758(ST5), 1759(ST5), 1760(ST5), 1761(ST5), 1762(ST5), 1763(ST5), 1764(ST5), 1765(WW4), 1766(WW4), 1767(WW4), 1768(WW4), 1769(WW4), 1770(WW4), 1771(WW4), 1772(WW4), 1773(WW4), 1774(IR3), 1775 (IR3), 1776(SA5), 1777(SA5), 1778(SA5), 1779(SA5), 1780(SA5), 1781(WW4), 1782(SA5), 1783(SA5), 1784 (IR3)[c], 1785(WW4)[c], 1786(SA5)[c], 1787(ST5)[c], 1788(IR3), 1789(WW4).

OCTOBER: 1790(EM4), 1791(EM4), 1792(EM4), 1793(EM4), 1794(EM4), 1795(HW3), 1796(HW3), 1797(HW3), 1798(HW3), 1799(HW3), 1800(HW3), 1801(HW3), 1802(HW3), 1803(HW3), 1804(HW3), 1805(HW3), 1806 (HY5), 1807(HY5), 1808(HY5), 1809(HY5), 1810(HY5), 1811(HY5), 1812(SM4), 1813(SM4), 1814(ST6), 1815 (ST6), 1816(ST6), 1817(ST6), 1818(ST6), 1819(ST6), 1820(ST6), 1821(ST6), 1822(EM4), 1823(PO5), 1824 (SM4), 1825(SM4), 1826(SM4), 1827(ST6)[c], 1828(SM4)[c], 1829(HW3)[c], 1830(PO5)[c], 1831(EM4)[c], 1832(HY5)[c]

NOVEMBER: 1833(HY6), 1834(HY6), 1835(SA6), 1836(ST7), 1837(ST7), 1838(ST7), 1839(ST7), 1840(ST7), 1841(ST7), 1842(SU3), 1843(SU3), 1844(SU3), 1845(SU3), 1846(SU3), 1847(SA6), 1848(SA6), 1849(SA6), 1850(SA6), 1851(SA6), 1852(SA6), 1853(SA6), 1854(ST7), 1855(SA6)[c], 1856(HY6)[c], 1857(ST7)[c], 1858 (SU3)[c].

DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4), 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867 (ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876 (WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(HY7)[c], 1881(SM5)[c], 1882(ST8)[c], 1883(PP1)[c], 1884(WW5)[c], 1885(CP2)[c], 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

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c. Discussion of several papers, grouped by divisions.